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Abstract. A Bremsstrahlung spectrometer using k-edge and differential filtering has been used with Image Plate dosimeters to measure the x-ray fluence from short-pulse laser/target interactions. An electron spectrometer in front of the Bremsstrahlung spectrometer deflects electrons from the x-ray line of sight and simultaneously measures the electron spectrum. The response functions were modeled with the Monte Carlo code Integrated Tiger Series 3.0 and the dosimeters calibrated with radioactive sources. Electron distributions with slope temperatures in the MeV range are inferred from the Bremsstrahlung spectra.

Introduction

In the fast ignition concept[i], a picosecond-scale laser pulse is used to heat a compressed 300 g/cc DT plasma and ignite a hot spot in the fuel. The laser interacts with the preformed plasma near the relativistic critical surface and deposits its energy into hot electrons, which propagate to the core and deposit their energy. Hydrodynamic simulations have shown that 1-3 MeV electrons have the ideal range for efficient deposition in the hot spot[ii]. The determination of laser-produced hot electron energy spectrum and conversion efficiency is therefore critical to assessing the feasibility of fast ignition.

The energy spectrum of hot electrons generated in the interaction of a short-pulse laser with a solid target has been previously measured or inferred using a variety of techniques, including electron spectrometers[iii,iv], nuclear activation[v], differentially filtered Bremsstrahlung spectrometers[vi], buried fluorescent foils[vii], proton emission spectra[viii], and combinations of the above. These measurements are useful for measuring various components of the electron spectra. For the 1-3 MeV electrons of interest, however, Bremsstrahlung spectrometers are more useful; the vacuum electrons measured by electron spectrometers are severely affected by MV potentials, and nuclear activation is sensitive to energies higher than those of interest to fast ignition.

We report here on the adaptation of a Bremsstrahlung spectrometer that uses Z and differential Pb filtering to determine the x-ray spectrum up to an MeV. This paper will describe the design of the instrument, review the calibration of the spectrometer, and discuss the simulations and analysis techniques to determine the energy spectrum (usually quantified as the slope temperature) in the regime of interest.

Spectrometer Design

A diagram of the Bremsstrahlung spectrometer is shown in Figure 1. The spectrometer consists of 13 filters of increasing Z from Al to Pb, and then increasing thicknesses of Pb for differential filtering. The filters are 1 inch square with a 250 µm sheet of Mylar taped to both faces to minimize the contribution of secondary electrons < 150 keV. This design was primarily adapted from R. Nolte[ix], where Thermoluminescent Detectors (TLD's) held in PVC trays were used as dosimeters. In our design we use Fuji BAS-MS Image Plates. The image plates have higher sensitivity than the TLD's and their spatial resolution allows for verification of diagnostic alignment. The image plates and filters are stacked in a 6 mm thick interlocking Lexan cartridge loaded into a 1.8 cm thick Pb box which shields up to 2 MeV photons. The Lexan cartridge allows for rapid loading and unloading of spectrometer, is light-tight to preserve the image plate data, and reduces the noise from scattered secondary electrons in the Pb

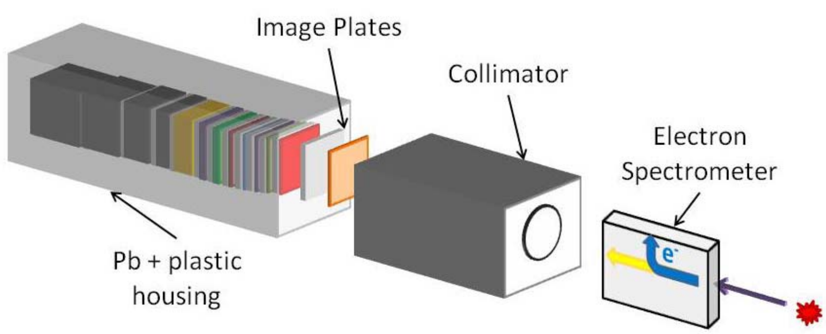

Figure 1. A diagram of the Bremsstrahlung spectrometer. The image plates are in a Lexan cartridge that fits into the Pb housing. The electron spectrometer deflects incident electrons.

shielding. A 12.5 cm long Pb collimator with a ½" diameter hole is also used to reduce noise from fluorescence off the vacuum chamber walls. In our experiments strong electron beams that escape the target are also present along with the Bremsstrahlung emission. We use a modified electron spectrometer to deflect incident electrons and also to compare the vacuum electron spectra along the same line of sight as the Bremsstrahlung spectrometer. A 6 mm thick Teflon block is placed in front of the Bremsstrahlung spectrometer to stop any additional electrons.

Dosimeter Calibration

BAS-MS image plates use a $BaFBr_{0.85}I_{0.15}$ phosphor layer. When exposed to x-rays, electrons in the phosphor layer are excited to a metastable state, where absorption of red light results in emission of blue light. The image plates are light and time sensitive, and good procedural controls are required for proper dosimetry. Following exposure, the image plates are kept in the light-tight Lexan cartridge and wrapped in a heavy cloth to prevent stray light from erasing the plates. They are scanned with a FLA-7000 image plate scanner which reads out PhotoStimulated Luminescence values (PSL's) by exposing the plates with a red laser. Since image plates fade with time, the fade curve was measured from 5 to 50 minutes by exposing the image plates for 32 sec to a filtered Cs-137 (662 keV) source. It was found that they fade about 20% in the first 30 minutes and then level off from 30 to 50 minutes. The image plates are thus scanned between 30 and 50 minutes after exposure on the flat part of the fade curve. We also assume in our analysis that the reading off the image plate is proportional to the total energy deposited in the active layer. To test this assumption and calibrate the plates, they were exposed to a Cd-109 source (22 keV) and a filtered Cs-137 source for 60 and 32 seconds, respectively, and scanned at exactly 30 minutes after the start of exposure. Using a 1-D monte carlo simulation from the Integrated Tiger Series 3.0[x] code package, the total energy deposited is compared to the PSL readout. The ITS code tracks electron and gamma ray showers, including such physics as elastic and Compton scattering, pair production, and x-ray fluorescence. The calibrations with the two sources were consistent, giving 1.47 ± 9% MeV/PSL for the Cd-109 source and 1.24 ±15% for the Cs-137, where the larger error bar from the Cs-137 exposure is from uncertainties in the activity of the source.

Simulation of Response Matrices

The response of the spectrometer to electrons incident on the target is broken down into 2 components. The Spectrometer Response Matrix (SRM) is calculated in 1-D using ITS and models the response of the image plates to incident photons. This response is shown in Figure 2. Each of the 13 lines corresponds to the response of the image plate behind the different filters. The SRM is built up by simulating the energy deposition in the active layer of the 13 image plates in response to 150 logarithmically spaced photon spectral bins from 1 keV to 100 MeV. The second component, the Target Response Matrix (TRM), is modeled in 3-D with ITS for each target type. 80 logarithmically spaced electron spectral bins from 10 keV to 100 MeV are injected normally into a 30° full cone angle from a 8 µm diameter source. The Bremsstrahlung spectrum into a 5° cone angle off the rear surface is calculated for the photon emission. The SRM and the TRM are multiplied together to obtain the full response matrix for the electrons.

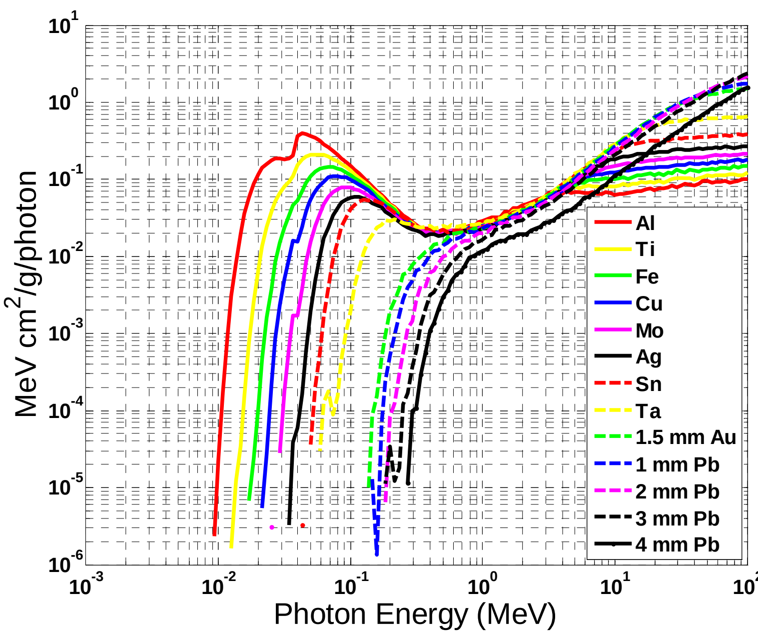

Figure 2. Spectrometer channel response (SRM) calculated from ITS 3.0. Each curve represents the energy deposited in that layer by the photon spectrum.

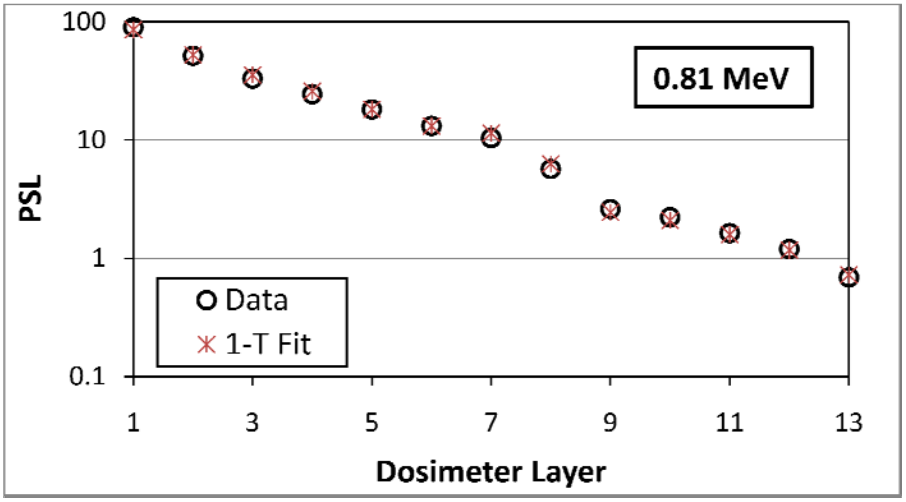

Figure 3. A 1-T Boltzmann distribution provides a good fit to the measured data under our experimental conditions.

The mean deposition values from each of the 13 images plates are taken as the measured data. The electron spectra can be back calculated a number of ways, including fitting sample spectra and maximum entropy techniques. For our experiments, we have found that a 1-temperature Boltzmann distribution of electrons provides a good fit to the measured data. Figure 3 shows the fit to a sample shot where an Al/Cu/Al sandwich target was irradiated with 57 J of 1.06 µm light, 0.7 ps, on the TITAN laser at Lawrence Livermore National Laboratory. A Boltzmann distribution of electrons with a 0.81 MeV slope temperature provides a good fit to the data. Other distributions, such as a 1-D relativistic Maxwellian, also fit the data with a very similar slope temperature. The sensitivity of the measured distribution to spectral shape is still under investigation. The actual Bremsstrahlung spectrum can be calculated by multiplying the fitted spectra by the TRM. Alternatively, the x-ray spectra can be inferred using maximum entropy techniques from only the SRM.

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